

# Abstract

## Coal Particle Flow Patterns for O<sub>2</sub>, Enriched, Low NO<sub>x</sub> Burners

Professor Jennifer L. Sinclair  
Stephanus Budilarto, PhD Student  
Purdue University  
School of Chemical Engineering  
West Lafayette, IN 47907-1283  
Phone: (765) 494-2257  
Fax: (765) 494-0805  
[jlds@ecn.purdue.edu](mailto:jlds@ecn.purdue.edu)

Professor Jost Wendt  
Greg Ogden, PhD Student  
University of Arizona  
Department of Chemical Engineering  
Tucson, Arizona 85721  
Phone: (520) 621-4422  
Fax: (520) 621-6048  
[wendt@engr.arizona.edu](mailto:wendt@engr.arizona.edu)

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The focus of this research is to develop tools that allow prediction of coal particle flow patterns in pulverized coal burners using oxygen enriched “air” as an oxidant, and to optimize these coal patterns to minimize NO<sub>x</sub> emissions. Purdue University is performing cold flow diagnostics and modeling and the University of Arizona is conducting hot flow tests, on an identical configuration. This collaborative work allows detailed laser Doppler velocimeter (LDV) cold particle flow and velocity measurements to be compared to hot, coal combustion data. In this work, we are investigating the effects of oxygen enrichment on pulverized coal particle flow fields, flame shapes and their subsequent NO<sub>x</sub> emissions.

NO<sub>x</sub> formation is preferred over N<sub>2</sub> formation when devolatilization occurs in a fuel lean environment. NO<sub>x</sub> formation during devolatilization has been shown to be both kinetic and mixing limited. The dependence of NO<sub>x</sub> formation on the local oxygen concentration suggests that combustion aerodynamics are important in controlling NO<sub>x</sub> emissions. Aerodynamics controls both the mixing between the fuel and the oxidizer and particle trajectories. In particular, near field aerodynamics have the greatest effect because coal devolatilization occurs in this region. The near field aerodynamics are controlled by jet inlet parameters, which for coaxial jet burners include:

1. Diameter ratio of the annular section to central nozzle ( $d_o/d_i$ )
2. Velocity ratio of the annular jet to the central jet in a coaxial jet ( $VR = U_{go}/U_{gi}$ )
3. Magnitude of the annular and central jet velocities
4. Swirl number
5. Burner geometry

Particle size has also been shown to affect NO<sub>x</sub> emissions, which tends to increase with decreasing particle size. Simultaneous changes in the size, shape, and density of the coal particles during devolatilization complicate the study of particle flow behavior since the changes are also accompanied by changes in the gas-solid interaction. Therefore, in order to have a good understanding in the NO<sub>x</sub> formation in the near-field region, firstly, we need to understand the effect of particle size, particle size distribution, and particle shape on gas-solid interaction under cold-flow conditions. Investigating this

particle size effect, as well as the effect of jet inlet parameters, has been the focus of the work to date at Purdue University.

At Purdue University, cold flow experiments have been conducted varying the velocity ratio of the annular jet to the central jet by varying the volumetric flow rate of the annular stream. Glass bead particles, 70 micron in size, have been used. The mass loading of particles in the central jet was maintained at 0.5 and the velocity ratio was varied between 0 and 1.8. LDV measurements indicate that although the gas phase turbulence increases with increasing velocity ratio, the cross-stream dispersion or spreading of particles is the same for all velocity ratios, indicating that turbulent diffusion does not play a role for particles in this size range. This behavior is consistent with particle Stokes numbers greater than 10 for these 70 micron particles. The next set of experiments involves investigating the cross-stream dispersion of 25 micron particles with particle Stokes numbers on the order of one. In these experiments we expect to see a large variation in particle dispersion with velocity ratio.

A flow visualization system has also been set up on the jet flow apparatus at Purdue University. This system allows for observation of gas vortical structures and how these structures vary with changes in the inlet parameters. The flow visualization system also allows for observation of particle dispersion and spreading. Flow visualization with the 70 micron glass beads confirmed that the particles were not following the gas flow field.

Efforts to date at the University of Arizona have focused on the construction of a novel 18" ID hot wall furnace for conducting the hot-flow experimental activities of this project. Construction of this new furnace has required extensive planning to ensure that the furnace configuration has sufficient flexibility for all aspects of the research project. The furnace has a 3' hot section with controllable wall temperature up to 1000 deg. C and a full-length quartz window for flow visualization. Air preheat is provided by a 6 kW circulation heater; the heater is sized to provide combustion air at the burner inlet at temperatures up to 1000°F. In addition to four stationary ports equally spaced down the side of the hot section, the furnace is equipped with a translating sampling stage. The translating stage runs the full length of the hot section of the furnace and is located at a right angle to the stationary ports and directly opposite the optical window described below. This configuration essentially cuts the furnace in half which complicated construction of the hot section as both sections had to be carefully positioned to mate into the furnace lid and base. The burner consists of a fuel injection tube surrounded by the secondary air. The burner design includes variable sleeves for both the primary (transport) and secondary (combustion) air streams. Thus, the velocity of the combustion air can be varied by selecting a wider or narrower combustion air sleeve without affecting the primary air flow conditions. A 3' cool section follows the hot section. Continuous emissions monitoring of CO, NO<sub>x</sub>, CO<sub>2</sub> and O<sub>2</sub> are possible. The furnace capacity is 17kW with 2kg/hr of coal.

Natural gas runs were first made in the furnace at the University of Arizona to check furnace operation while the coal particle feeder was under order. Stable attached flames were produced by co-firing natural gas with 750 deg. C walls and 130 deg. C air preheat. Coal runs have recently been conducted in the furnace producing 1-1.5' stable detached coal flames when feeding 1 kg/hr of coal with 900 deg. C walls and 423 deg. C air preheat. Future work includes conducting a parametric analysis to evaluate the flame stability and resultant emissions varying wall temperature, air preheat temperature, the velocity of the combustion air (as in the cold flow experiments) and the oxygen partial pressure in the combustion air.

## **Presentations and Articles**

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Stephanus Budilarto, PhD Student  
Purdue University  
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Phone: (765) 494-2257  
Fax: (765) 494-0805  
[jlds@ecn.purdue.edu](mailto:jlds@ecn.purdue.edu)

Professor Jost Wendt  
Greg Ogden, PhD Student  
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Tucson, Arizona 85721  
Phone: (520) 621-4422  
Fax: (520) 621-6048  
[wendt@engr.arizona.edu](mailto:wendt@engr.arizona.edu)

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“The Effect of Velocity Ratio and Particle Size on Particle Motion in a Coaxial Particle-Laden Jet”, 2001 Annual AIChE Meeting, Reno, Nevada, November 2001 (to be given).

“The Effect of Varying Velocity Ratio on the Flow Behavior of Particle-Laden, Turbulent, Coaxial Jets”, 4<sup>th</sup> International Conference on Multiphase Flow, New Orleans, LA, June 2001.

“Velocity Ratio Effect on Gas and Particle Motion in Two-Phase Turbulent Co-Axial Jets”, 2000 Annual AIChE Meeting, Los Angeles, California, November 2000.

“Comparison of Velocity vs. Momentum for Stabilizing Turbulent Natural Gas Flames”, AFRC Meeting, Newport Beach, California, June 2000.

“Optimization of Coal Particle Flow Patterns in Low No<sub>x</sub> Burners”, AFRC Meeting, Tucson, Arizona, April 1999.

Budilarto, S. and J. Sinclair, “Evaluation of Turbulence Models and Ad-Hoc Theories in Predicting Recirculation in Axisymmetric, Confined Jets”, J. Fluids Engineering (2001) submitted.

## **Students Receiving Support from the Grant**

Stephanus Budilarto, PhD Student, Chemical Engineering, Purdue University  
Greg Ogden, PhD Student, Chemical Engineering, University of Arizona